ERDC/TN ANSRP-10-2
May 2010

Predicting the Potential for Invasive Species Establishment by Using Environmental Tolerance Data

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PURPOSE: This study summarizes how a relatively simple model can be used to predict invasion potential by an aquatic nuisance species.

INTRODUCTION: The spread and subsequent unlikely eradication of alien species from recently invaded ecosystems reinforces the need for predictive tools to help management personnel evaluate associated detrimental impacts. It is estimated that in most countries 102-104 nonindigenous species have been documented, and numbers should increase with expanding global trade and travel (Lodge 1993). Although only a small percent (usually < 10 percent) are invasive (Williamson and Fitter 1996), some have enormous economic and ecological impacts (Office of Technology Assessments (OTA) 1993; Ricciardi and Rasmussen 1998). For these reasons a need exists to determine which species will be introduced and which will cause impacts in order to allocate resources for prevention, detection, management, and control efforts (Grosholz and Ruiz 1996; Ricciardi and Rasmussen 1998; Colnar and Landis 2007).

Many models, simple and complex, have been developed to predict invasions of nonindigenous species over large regional areas. For example, invasive species attributes combined with transfer vectors and climate matching were used to predict potential distribution of common carp (*Cyprinus carpio L.*) in Australia (Koehn 2004). Attributes that were examined included: invasion history, environmental tolerances, genetic variability, sexual maturity, generation time, growth rate, reproductive capacity, diet, gregariousness, dispersal mechanisms, and use by humans. Vectors were either natural movement within watersheds or more frequently via accidental or deliberate release by anglers or through importation and release of ornamental "Koi" carp (Koehn 2004). Finally the authors found climatic conditions that exist in Australia matched other regions of the world where common carp have established, thus increasing the likelihood that the species would become established and widespread throughout the continent (Koehn 2004).

In recent years additional tools using mathematical techniques have been developed to estimate the geographic distribution of a species. For the continental United States, a niche modeling program called GARP (Genetic Algorithm of Rule-Set Prediction) was used to develop predictive range maps for invasive species such as *Aristichthys nobilis* (Bighead Carp), *Channa* spp. (Snakehead), *Hypothalmichthys molitrix* (Silverhead Carp), *Limnoperna fortunei* (Asian mussel) and *Potamopyrgus antipodarum* (New Zealand mud snail) (Chen et al. 2007; Loo et al. 2007). A GARP model was also used to estimate potential range expansion of *Dressiena polymorpha* (zebra mussels) following their introduction into the Great Lakes region (Drake and Bossenbroek 2004). Eleven environmental and geological variables were used to predict invasion risk in other regions of the United States. The model predicted that risk would be high throughout the Midwest, in three western catchments (the Colorado River, the Columbia River, and the Central Valley of California), the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAY 2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **Predicting the Potential for Invasive Species Establishment by Using Environmental Tolerance Data**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Engineer Research and Development Center,Vicksburg,MS**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Southeast, and along the eastern seaboard. A current distribution map (U.S. Geological Survey (USGS) 2008) indicates that zebra mussels are found primarily in the Midwest but have expanded south into Louisiana, west into Oklahoma, Kansas, Nebraska, and South Dakota, and east to the Vermont border. As of 2008, zebra mussels were discovered in three locations in the western United States; the San Justo Reservoir in central California, the Pueblo Reservoir in Pueblo, Colorado, and Grand Lake, Colorado, 50 miles northwest of Denver (USGS 2008). Establishment has only been confirmed for San Justo Reservoir.[1] Zebra mussels can survive long distance transport into new regions on boat trailers or engine props, but to date there have been no major successful invasions throughout much of the Southeast, the eastern seaboard, or large areas of the western United States. Of the three western catchments, the least at risk system was the Colorado River. In fact the model indicated that zebra mussels were not likely to establish west of 100º W, which led Drake and Bossenbroek (2004) to suggest that federal resources to control the spread of zebra mussels should be concentrated in the Southeast, the three western river catchments, and in regions where zebra mussels already exist.

In a more recent attempt to forecast the western spread of zebra mussels, Bossenbroek et al. (2007) used a gravity model of boater movements. This was in part based on previous predictions that invasions were likely to result from overland "jumps," especially those involving boating activities (Buchan and Padilla 1999; Johnson et al. 2001). The model focused on transient boats (i.e., those that are used for < 1 day and stored on a trailer when not in use) rather than resident boats (i.e., those that reside in waters for 1 to 2 months or longer and are rarely moved out of the resident waterbody). The model predicted that western expansion via transient boats was likely to be slow because western watersheds have much lower visitation rates than eastern watersheds. However, the authors did emphasize that although movement may be slow, the impact from establishment at invaded sites may be unusually high because populations will likely be moderate to high (Bossenbroek et al. 2007). Potential zebra mussel densities in western lakes were derived from a model that used environmental parameters to characterize the sites. They fell within predicted ranges for lakes known to contain zebra mussels in the eastern United States.

The above-mentioned models that predict invasive species movements over large geographic regions provide site managers with some indication whether invasion into a certain region is a possibility and thus they can begin to develop contingency plans prior to an invasion. These preemptive plans can be implemented to prevent or limit the possibility of invasive species establishment and spread. It should be emphasized that even though a region may have a high probability for invasion, characteristics of a site will more accurately indicate conditions favorable to invasive species establishment and reproduction. This requires documentation of the physical and chemical conditions found at a particular site. Once these are measured they can be compared to the environmental tolerances of individual species, and predictions can be made as to whether colonization potential for a particular species is low, medium, or high. Depending on the probability of a species successfully invading an ecosystem, appropriate protocols can be recommended dictating frequency and intensity of site monitoring.

Zebra mussels offer an excellent example of how environmental parameters can be used to develop a simple model to determine whether a species can survive and/or thrive at a particular site (Claudi

[1] Personal communication. 2009. F. Nibbling, Research Biologist. U.S. Bureau of Reclamation.

and Mackie 1993). For zebra mussels, the most important parameters that can be measured include annual variations in temperature, calcium, and pH. Lesser variables include nutrient levels, turbidity, dissolved oxygen, salinity, and water velocity. Although zebra mussels have well-defined environmental preferences, they can tolerate a wide range of conditions, and these parameters can be used to develop a simple model, hereafter called the zebra mussel calculator, to determine vulnerability of a site to invasion. The calculator is available on the Aquatic Nuisance Species Information System (ANSIS) compact disk, free by request from the U.S. Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180, attn: Sherry L. Whitaker or by email to *Sherry.L.Whitaker@usace.army.mil*.

ZEBRA MUSSEL CALCULATOR: The calculator model provides most reliable site invasion potential if the input is derived from robust historical data. Claudi and Mackie (1993) recommend that site information should be collected regularly for 2-5 years (preferably daily to weekly) to provide month-to-month variations and monthly minima and maxima for each variable. Built into the calculator are environmental tolerance data on five variables: pH, calcium content, dissolved oxygen, salinity, and temperature. While site-specific information on all five variables would be highly desirable, the calculator only requires input on three of the five variables to determine the vulnerability of a site to invasion by zebra mussels.

Using information derived from Claudi and Mackie (1993), the calculator rates risk of infestation from low to high, based on the values found in Table 1. After entering information on at least three of the five variables, the calculator rates site risk on a scale from 0 to 10. If a variable is omitted, the calculator uses a corrected score by evaluating the habitat scores on the same scale as habitats that have data sets for all the physical variables involved. A score of 0 identifies a site as having extremely low risk of invasion, whereas a score of 10 would identify a site at extremely high risk of invasion. Specifically a site is at low risk of infestation if the score = 0 to < 3, at moderate risk if the score = 3 to < 8, and at high risk if the score = 8 to 10.

Table 1. Environmental tolerance values for pH, calcium (Ca^{++}), dissolved oxygen (DO), salinity, and temperature that are used to determine level of site risk to zebra mussel invasion.

Risk	pH	Ca[1] mg/l	DO mg/l	Salinity ppt	Temperature[2]
Low	<6.7999999 or 9.0 – 10.0	<20.999999	<4.5999999	>3	<1
Medium	6.8 – 7.3999999	21 – 54.999999	4.6 - 8	>1-3	1 – 3.999999
High	7.4 – 8.9999999	>55	>8	0 - 1	>4

[1] The conversion formula for carbonate concentrations is $CaCO^3 * 0.4 = Ca^{++}$.
[2] The number of months temperature exceeds 12 ºC.

Another important component of site assessment is monitoring. Monitoring involves the collection and analysis of repeated observations or measurements so as to evaluate changes at a specific site. It is a necessary first step in developing a comprehensive management scheme for invasive species. Initial monitoring establishes baseline data for a site and might include chemical, physical, and biological properties. Subsequent follow-up monitoring on a regular basis would then be used to determine if site characteristics have changed and/or management objectives are being met. Regular

monitoring has also been mandated through several pieces of legislation including the Endangered Species Act, the Federal Land Policy and Management Act of 1976, and the National Environmental Policy Act of 1969.

Certain monitoring procedures can be implemented whether zebra mussel invasion risk is low, medium, or high. Monthly monitoring of pH, calcium, dissolved oxygen, salinity, and temperature can be used for annual inventory site assessments and to determine if risk of invasion has changed. If the risk is medium or high, the inventory should be made on a biannual schedule. It is imperative that site managers keep abreast of changes in zebra mussel abundance or distribution within a local area. Information is easily accessed via web sites that monitor invasive species. Two useful websites for aquatic invasive species are the Stop Aquatic Hitchhikers (*http://www.protectyourwaters.net/*) and the USGS website (*http://nas.er.usgs.gov/*). These sites provide current information on invasive species threats and movements into new areas. If threats are imminent, monthly monitoring for zebra mussel adults and veligers would be in order, particularly at locations where boat traffic is high. If risk is moderate or high, a rapid response strategy should be in place so as to quickly address an invasion. Eradication may be possible if an invasion is detected early and a response plan is already in place. In the event of an infestation, long-term control strategies should also be thought out in advance. This often means establishing a working relationship with state and local agencies and interested stakeholders.

Once established, nonindigenous aquatic nuisance species may spread rapidly and cause unanticipated negative biological and economic impacts. The USGS website currently has information on 1532 nonindigenous aquatic vertebrates and invertebrates as well as 141 nonindigenous aquatic plants. Included in the information are brief descriptions of the species, occurrence data, means of introduction, current status, impact of introduction, remarks, and references. Links are also provided to other web sites that have information on the species. Documentation provided at these sites is almost exclusively distributional in nature. While it is valuable to know where a species occurs in the United States, site managers might have more use for predictive tools like the zebra mussel calculator to determine if a species might establish and thrive at a specific location. Requisite to developing predictive tools, however, is availability of data on environmental tolerances for each species. In examining the available literature for a small number of nuisance aquatic species (Shearer and Grodowitz, in preparation), it became readily apparent there were serious data gaps even for well-studied species such as the swamp eel (*Monopterus albus*), round goby (*Neogobius melanstomus*), and the New Zealand mud snail (*Potamopyrgus antipodarum*). Filling these gaps will hopefully encourage the development of additional “calculators” that can aid in determining risk of invasion by other aquatic nuisance species.

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This technical report should be cited as follows:

> Shearer, J. F., and M. J. Grodowitz. 2010. Predicting the potential for invasive species establishment by using environmental tolerance data. ANSRP Technical

Notes Collection. ERDC/TN ANSRP-10-2. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://el.erdc.usace.army.mil/ansrp/ansrp.html*.

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